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ENHANCING THE EFFECTIVENESS OF THE INDIVIDUAL IN THE ARCTIC THROUGH CLOTHING AND EQUIPMENT

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It has been said that up to 75% of a soldier's energy and attention in the extreme cold is taken up by mere survival. Whether this is a correct figure or not, it may serve to illustrate the general character and dimension of the challenge presented to the developer of clothing and equipment for soldiers who must be prepared to fight in such climates.

One major concept of functional design of cold climate clothing which can be utilized to reduce this loss of efficiency is to extend the period during which the clothing will keep the body warm when the man is inactive.

The classical solution to this problem, as practiced in civilian-type clothing, has been to add more insulation as the temperature drops lower. Taken by itself without consideration of other factors, however, this solution can be self-defeating.

The range of temperatures for which cold weather clothing is needed extends from +65° F to -65° F — a total range of 130 degrees F. The range of temperature within even as short a span of time as a week, while a soldier is wearing a given set of clothing, may vary from 40 to 50 degrees F or even more. There must, accordingly, be a capability of varying the amount of insulation in the clothing system required to meet this range of temperatures.

There must also be the capability of meeting the even greater moment-to-moment variability in body activity. Measured in terms of heat output, the level of body activity may vary from 60 kcal/m^2/hr for an inactive man to a potential of eight times that much, of 480 kcal/m^2/hr for a very active man.

The effect of this variation in body heat output upon the need for protective clothing was well illustrated a number of years ago in the classic illustration of the mittens. The highly active man needs little protection for his hands. The inactive man simply

cannot be provided with enough protection for his hands if he is inactive for a long period of time. For an inactive man at low temperatures, therefore, a good deal of insulation is required. However, the inactive soldier may, at any time, become very active. Unless the clothing system can be designed to allow these "spurts" of heat output to pass out of the clothing, the body will accumulate heat and respond by sweating. Sweat which cannot evaporate is ineffective in counteracting the heat build-up.

More significant, if it accumulates in the clothing it will drastically reduce the insulation which the clothing is intended to provide. Then, when the subject returns to a lower activity level and lower heat production, and really needs the full measure of his clothing insulation, he will find that the sweat has reduced the effectiveness of the insulation below what it was when dry, and quite probably below the required level for adequate protection. This problem is often referred to as "after-exercise chill."

The providing of effective insulation, therefore, actually calls for a highly efficient insulation system when the man is inactive, combined with an efficient design-and-materials system for the dissipation of body heat when the man is very active.

It is generally understood today that the effective insulation in a clothing system is comprised simply of trapped dead-air spaces. We therefore want a design-and-materials system having the highest possible ratio of air spaces per unit of weight. In other words, we need all of the trapped-air spaces we can get without having to pay for them in weight of materials.

There are, then, three major functional concepts in making cold weather clothing: first, to find the lightest weight insulating material it is possible to produce; second, to trap the dead air in spaces between loose-fitting layers of clothing, so that when the man is active the spaces between layers can act as channels or chimneys (the closer to the skin the better) by which the heated air can move to escape through vents; and third, to design the clothing so that it can easily be opened for venting warm, moist body air to the surrounding atmosphere, and allow cold outer air to penetrate close to the skin surface for cooling during times of high body activity.

There are other essential requirements which should not be overlooked, such as wind resistance of the outer layer, so that the trapped-air spaces may not be disturbed; water resistance of the outer-layer fabric, so that external moisture will not get in and lower the insulating value of the material; launderability; speed of drying when materials do get wet; and so on.

The most efficient system, with a large volume of air spaces trapped in the clothing, will tend to be bulky — just the opposite of the tight-fitting stretch materials now being promoted for civilian "appearance-type" outdoor clothing. It will be comprised of a number of layers, rather than just a single added garment (a system in which these layers can be added or removed to adjust to body activity and to temperature variations), and as light in weight as possible.

We have moved through four types of insulating material since World War II in this search for an ideal type: an artificial fur pile fabric, a double-faced wool pile, a frieze fabric and a napped frieze.

However, the recent development of satisfactorily launderable battings of polyester fiber has provided perhaps the most important breakthrough since World War II toward increased efficiency of a cold weather clothing system. Liners made of these materials, weighing no more than a pound and a half to cover the entire body, will provide adequate insulation for an inactive man for a 30° drop in temperature. The insulation liners required to carry him down to -65° F will weigh only three pounds. (His extremities will still provide a problem however.)

We have tried to use this same insulating material in sleeping bags. However, it lacks the desirable characteristic of waterfowl down and feathers of being compressible to small bulk. This means that sleeping bags made of it, having the requisite thickness for extreme cold, have nearly 30% extra bulk compared to the standard cold weather sleeping bags. However, through the ingenuity of Dr. Terris Moore, consultant to the Natick Laboratories, a way has been found to utilize this polyester batting inside the inflatable pad. By attaching a full inch of this insulating batting to the upper surface, we can provide the equivalent of two clo* of insulation underneath the man when the pad is inflated. This batting in the pad keeps convection currents of air inside the pad from being a source of heat loss to the man.

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* An arbitrary unit of thermal insulation, used in expressing the thermal insulation value of clothing. A suit of clothing has a thermal insulation value of one clo when it will maintain in comfort a resting-sitting human adult male whose metabolic rate is

We have, then, as the biggest unsolved problem for research in cold weather clothing, this matter of developing a really efficient system for getting rid of the rapidly generated heat when the wearer goes quickly from a state of inactivity to high activity. It is an area of clothing design research where a great deal of work is needed.

The simple answers of ventilating by use of bellows run by some aspect of body movement or by the use of a power-driven fan, for which the man carries the fuel and the engine, present difficult engineering problems, some of which are being studied under our thermalibrium program.

A most promising approach appears to be the "Climastat" principle proposed by Robert L. Woodbury. The "Climastat" system proposes using an insulating layer of lightweight, non-wettable, impermeable foam material having a large number of "holes" punched through it in which air is trapped when the man is motionless, but through which air circulates when he is active.

During body movement, the pressure differentials inside the clothing and the turbulence created by movement of the clothing as the man walks or runs would tend to cause a continuing interchange through these holes of the warm, moisture-laden air near the body and the colder air in the outer layers of clothing. With proper venting, warm air could be forced out and cold air brought in, in some kind of controlled fashion. Concepts of design by which such a system could be optimized, the right size and location of holes in the insulating material, and the selection of the material itself have posed problems for materials and clothing design research which appear formidable at this time and yet which should be capable of solution with adequate research. The major problem we have encountered up to this point with the "Climastat" approach has been in obtaining the range of needed adjustment within the theoretical scope of this approach.

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approximately 50 kilogram calories per square meter of body surface per hour, when the environmental temperature is 70° F. In terms of absolute thermal insulation units, one clo is 0.18° C per square meter kilogram calorie per hour. (Blakiston's New Gould Medical Dictionary, First Edition, New York, McGraw-Hill Book Company, Inc., 1949.)

Related to the matter of insulation is the continuing effort to extend the period before the onset of fatigue, through lightening the weight of everything the soldier carries and so designing his clothing and equipment as to reduce energy expenditure in every possible way.

Many years of intensive studies of the design of load-carrying equipment and the proper placement of a load to be carried by a man have shown that placement of the load can have a significant effect on energy expenditure. For example, any weights placed on moving or swinging parts of the body, such as the mid-thighs, will cause three times the energy cost of a similar load placed on the back. Present load-carrying approaches attempt to distribute the weight evenly over the shoulders, back and hips of the carrier. To the extent that different designs of equipment succeed in balancing the load on the torso, they are essentially equal in their energy demands on the soldier.

There is little that can be done to conserve the energy of the combat soldier through different load-carrying designs, other than through lightening the weight of the equipment and improving its versatility. Our latest development has been the lightweight rucksack, which has reduced the weight of the Army rucksack from 7 lbs to 2-3/4 lbs.

This item has just completed tests at the Arctic Test Center with a favorable recommendation for adoption by the Army for arctic use. It has already been adopted for Special Forces use and has undergone extensive field use in South Vietnam. We are currently expanding the concept of a lightweight pack frame as part of a universal load-carrying system, in the development of load-carrying equipment for indigenous forces in Southeast Asia.

This matter of lightening the load of the combat soldier has recently been receiving a great deal of well-merited attention and does not need extensive comment here. It would be well to note, however, that one cannot always have his cake and eat it. The critical point is where this matter of lightening the load stands in terms of priority. If it is to have a high priority, something else may have to be given up. If you want a man to be fully comfortable at -65° F for 6 to 8 hours, he is going to have to carry around a lot of insulating material. However, if you can be content to keep him moderately comfortable and out of danger from cold injury at very low temperatures, the weight of his clothing can be reduced commensurately. The tendency to seek to give a man everything he needs for comfort, which unfortunately is typical of most armies in peacetime only, adds to the weight of what he must carry.

Beyond the matter of lightening the load as a means of conserving energy, there is a great need for research in clothing design to minimize energy expenditure. We have introduced slippery layers of nylon lining into the cold weather clothing system to reduce internal friction as the man moves his arms and legs, and with such action moves parts of his clothing over each other.

However, the energy expended in moving the clothing as part of normal body movement has never been measured, nor has adequate study been given to the determination of how to minimize such energy expenditure. Model systems for study of this problem can be developed, but extensive research is needed. A third approach to enhancing the effectiveness of the individual in the Arctic involves providing assurance that cold injury to the extremities can be positively prevented. Fortunately, a fundamental solution to the problem of cold injury to the feet through the sealed insulation boot was developed by Dr. Paul Siple and the late C. H. Bazett in 1944 as part of the Quartermaster research and development program. Although a practical boot was not developed until 1951, it was then made available to our forces in Korea. It contributed to the almost complete elimination of cold injury to the feet during the winter 1952-1953 and subsequent years.

While outright cold injury can now be almost entirely eliminated by the sealed insulation boot, there are hygienic problems connected with it. Daily or even more frequent change of socks is needed to minimize softening of the skin tissues. Ventilating of the boot has been attempted, but a satisfactory construction has not yet been achieved, nor would this fully solve the problem.

Natick Laboratories now have a program to develop a lighter weight version of the sealed insulation boot. However, a final type of lightweight, cold weather footwear, which fully meets the needs for protection and comfort, is going to require a great deal of further research and development.

There is also the problem of summer footwear for muskeg-type terrain. In the wet areas of the tropics, we expect the foot to always be wet and accordingly provide drainage outlets in the boot so that water can drain out to let the foot dry itself whenever it is possible to do so. In the typical muskeg areas of the North, however, ground water is much colder, and the solution for the jungle is neither a satisfactory nor a safe one. No present type of footwear, whether made of leather, fabric or rubber, really meets this requirement. It is an area in which we would like to have recommendations based on field experience.

The recent adoption of an all-purpose ski to satisfy the needs of both cross-country and alpine oversnow mobility lessens the logistical burden but does not resolve the dilemma of rapidly providing effective mobility to troops unaccustomed to oversnow travel by virtue of a warm climate background. Development of an all-purpose binding, which is still in the offing, will further simplify logistics but will not improve individual proficiency. The operational implications will persist where troops can be readily trained to use snowshoes, with a highly significant limitation in mobility, or else extensive training must be given to develop a competent military skier. Barring the development of some unforeseen technique for rapidly training men to ski well or the unlikely invention of some easy-to-use individual oversnow device, the level of individual oversnow mobility in the Arctic remains a command decision between the use of skis or snowshoes, with the attendant consequences in training requirements and degree of mobility.

The utilization of a person's fingers and hands in the Arctic is probably the most difficult single problem to be solved in clothing design. We have the diametrically opposed requirements of maintaining dexterity and tactility, and at the same time giving sufficient insulation to keep the hands warm.

We have recently adopted a principle of utilizing differential insulation in our curved handwear by placing lightweight insulating batting over the back of the hands where the big blood vessels come close to the skin surface. This has the advantage that added insulation at this point does not interfere with dexterity or tactility.

Another recent significant development has been a means whereby we can curve the fingers and palms of leather handwear to provide "natural hand" gloves and mittens. The importance of this became evident in our development of impermeable gloves for handlers of fuels for guided missiles several years ago. In this type of handwear only a minimum of muscular effort was needed to utilize the fingers for manipulating any type of equipment.

Through our invention of a new device for stitching leather and fabric gloves, we have been able to introduce this same natural hand shape into cut-and-sewn cold weather handwear. Here the back of the hand is 1-1/2 in. longer than the palm. The importance of this will be evident when one considers that the back of the hand lengthens 1-1/8 in. in bending the hand.

Currently, our interest in handwear is turning to the utilization of waterproof cold weather handwear. We have carried out extensive research in attempting to make leather waterproof, but because of the structure of leather, it has not been possible to achieve this. However, if greater efficiency in cold weather handwear is to be achieved, it will have to include the development of handwear that remains dry even after picking up and handling wet objects. Several approaches to this are being undertaken in connection with our current research and development program.

However, for many conditions in the extreme cold, particularly for the inactive man, there will simply not be enough heat in his body system to keep his hands warm. Accordingly, auxiliary heating is the only answer. We have developed a simple type of wired glove which can be worn as an insert next to the skin and which is furnished with thermostats which will prevent either overheating or excessive cooling. This glove either can be connected to a portable battery system or plugged into any power source that may be available. For vehicle drivers exposed to the cold, and for operators of other types of powered equipment, such auxiliary heating is clearly the most practical solution for the problem of keeping hands warm.

There is one further area where the effectiveness of the individual is definitely affected by his clothing; that is in the loss of sensory perception which he experiences in the cold from the clothing he wears. There is significant loss of hearing from the hood worn over his head, and there is substantial loss in the range of his vision from the shielding against the wind provided in his headgear.

We, who are concerned with clothing design, have tried to deal with these problems by providing flexibility and adjustability in the headgear. We have also sought to develop hearing cells which will both reduce attenuation of sound and amplify the sound coming to the man through his hood.

This is an area where far more study is needed from the standpoint of design than has been accomplished up to this point. Thus, no fully satisfactory head protection for the soldier in the Arctic has ever been developed. Our new insulating cap to be worn underneath the helmet is the first successful development which permits keeping the helmet stable and still provides essential warmth.

We are currently launching a program for an extensive study on the entire problem of protection, with particular attention to the protection of the head in the cold, in the interest of reducing the number of items involved and enhancing the sensory perception of the individual.

A more radical solution to providing body warmth in the Arctic is that of our thermalibrium clothing system. The thermalibrium concept, as formulated by our research group, is an approach to combining essential protective mechanisms into a single, total body clothing system. It envisions the use of three major components:

1. A combined protective headgear assembly.

2. A multi-functional garment and appropriate handwear, footgear and load-carrying equipment.

3. A lightweight, self-contained heat regulation device that can be integrated with the basic ensemble.

The headgear would consist of a well-insulated ballistic helmet with a built-in voice communication system, a protective face shield and a powered filtering system to purify the incoming air for breathing when the face shield is closed. A lung-actuated emergency breathing system would be built into the headgear assembly to be used if necessary.

The body clothing would consist of three separate multi-functional components: (1) a two-piece reversible overgarment with OG fabric on one side and a camouflage fabric on the other, (2) the basic ventilating ensemble and (3) a form-fitting knitted underwear.

Heat and moisture regulation inside the clothing system would be accomplished by circulation of conditioned air obtained from a lightweight, self-contained heating and cooling device integrated into the clothing system.

The inherent insulation properties of this over-all clothing system would be of such value that if the heat regulation device failed in extreme cold, the individual would not become a cold weather casualty; if the system failed, it would "fail safe."

When we consider the microenvironment and the soldier in its totality, it is evident that the separate equipment we are now furnishing for separate but related functions of clothing, sleeping gear, shelter and a heating system should be restudied in its totality so that a truly integrated system might be developed to serve these related functions.

At the present time the equipment we furnish the man for these functions weighs a total of 82 lbs per man. This figure includes the man's arctic sleeping gear, his individual clothing, one-fifth of the weight of an arctic tent, stove and gasoline for heating.

Under our present development programs, including the new integrated clothing system and the Moore sleeping pad, and a new type of tent, we can foresee this weight being cut by 20 lbs — a very sizeable saving.

Further reduction of this weight of clothing and equipment without significant impairment of the protection afforded to the individual soldier will require a great deal of research, on both materials and design concepts.

In summary, progress in this area is dependent heavily upon the results of materials research and development, particularly the production of new types of materials which can contribute greater efficiency in a cold weather system, and upon research in clothing design and construction. Research in clothing design for the extreme cold holds far more potential for enhancing the efficiency of the soldier than is generally recognized. It probably holds the key to making the arctic soldier a more efficient soldier, more than could be done by any new type of weapon or mechanical equipment that could be provided to him.

Also, there is a need for an organized approach to the science of clothing, as Dr. Newburg defined this area some years ago. It is difficult to apply scientific approaches in an industry which is, to a large extent, based upon crafts. For this reason, close collaboration of the clothing designer is needed with research people in the other areas which embrace what we call the biophysics of clothing: physiology, medicine, psychology, anthropology, human engineering, physics, military geography and textile technology.

The problems of protection of the man need to be studied as a whole instead of being dealt with solely within the partitions of separate scientific disciplines. Information in these various fields is largely scattered and uncorrelated; its existence is often unknown to workers in the field of clothing or to other workers in this cross-boundary area, and difficult to locate on a timely basis.

We are now creating an information center at Natick Laboratories in this area of the performance aspects of clothing and equipment in their use by the individual, and the properties of materials in relation to their use in clothing and equipment. We hope in this way to bring together information from all of the scientific disciplines which can contribute significantly to this area.

Through such interdisciplinary studies and research in this cross-disciplinary area of the biophysics of clothing, we believe that improved types of clothing and equipment can be developed which will further enhance the effectiveness of the individual in the Arctic.